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# Simplified Synthetic Testing Facility with Modified TRV Circuit

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**Abstract** – In order to develop a gas circuit breaker (GCB), the breaking performance of the short line fault (SLF) should be prioritized over that of the breaker terminal fault (BTF). In brief, it is necessary to evaluate the thermal characteristics of the insulating gas that is filled in a GCB. In the process of developing a GCB, many companies use the simplified synthetic testing facility (SSTF). In order to evaluate the SLF breaking performance of a GCB with a long minimum arcing time, a modifications to the conventional SSTF was proposed. In this study, we developed the SSTF with a modified transient recovery voltage circuit. The performance of the newly developed SSTF was verified by an $L_{90}$ breaking performance test on a rating combination of 170 kV, 50 kA, and 60 Hz.

**Keywords**: Breaker terminal fault, Gas circuit breaker, Modified transient recovery voltage circuit, Short line fault, Simplified synthetic testing facility

## 1. Introduction

In order to protect an extra or ultra-high voltage power system, a gas circuit breaker (GCB) is employed to break the fault current. These GCBs should essentially possess high-voltage insulation, and a low and high current breaking performance. The high current breaking performance is further classified into breaker terminal fault (BTF) and short line fault (SLF) breaking performance. In general, the types of breaking failure that occur after the zero-point current can be classified into thermal and dielectric breakdown. The success or failure of an SLF and a BTF interruption are determined by the thermal and the dielectric breakdown characteristics, respectively [1].

The breaking performance of the SLF is of more importance than that of the BTF. This is because the rate of rise of recovery voltage (RRRV) in the SLF is higher than that in the BTF. Therefore, it is necessary to evaluate the thermal characteristics of the insulating gas filled in the GCB.

A breaking performance test is essential during the development of a GCB. The test current is typically supplied by a facility known as the short-circuit generator, and the test voltage is supplied by a capacitor bank. However, these short-circuit generators require a significant construction and maintenance cost, periodic maintenance, and manpower.

This is the reason why many companies use the simplified synthetic testing facility (SSTF) nowadays. The SSTF uses an L-C resonant circuit for the test current supply and a capacitor bank for the test voltage. The most widely-used method in an SSTF is the parallel current injection circuit (or Weil-Dobke circuit). The basic circuit diagram of an SSTF is shown in Fig. 1, in which C, R, and L denote the capacitor, resistor, and inductor, respectively, and the subscripts i, v, and f denote current source, voltage source, and the transient recovery voltage (TRV) circuit, respectively. MS, ACB, Vd, Sh, and Gap denote the making switch, auxiliary circuit breaker, voltage divider, shunt, and spark gap respectively [2, 3]. The test circuit breaker for evaluating the breaking performance is denoted as TCB. The left side of the TCB shows the current source circuit for the test current supply, while the right side shows the voltage source circuit for supplying the test voltage. The TRV circuit consisting of Rf and Cf can be seen in Fig. 1. The TRV circuits can generate TRV waveforms defined by a two-parameter $(u_c, t_3)$ in IEC 62271-100.

In the case of a vacuum circuit breaker (VCB), the breaking performance can be easily verified with an SSTF. This is because the minimum arcing time of a VCB is relatively small (~2–3 ms). Fig. 2 shows the results of the breaking test of the VCB. The test was performed in a first current loop because the minimum arc time was small. The rms current value is 25 kA, the arcing time is 3 ms, and the maximum arc voltage is 30 V.

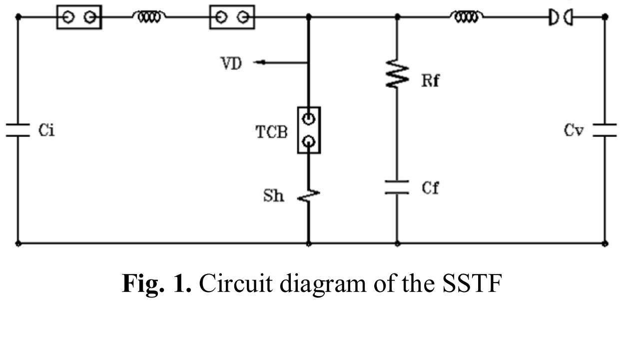


**Fig. 1.** Circuit diagram of the SSTF

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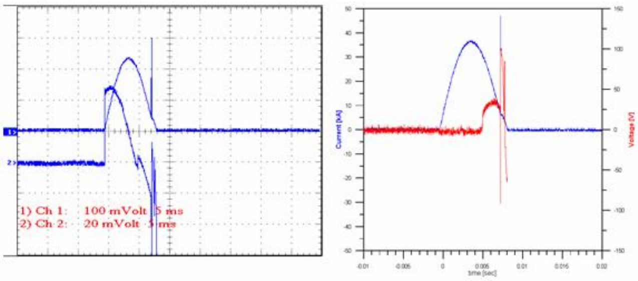



**Fig. 2.** Test result of the VCB

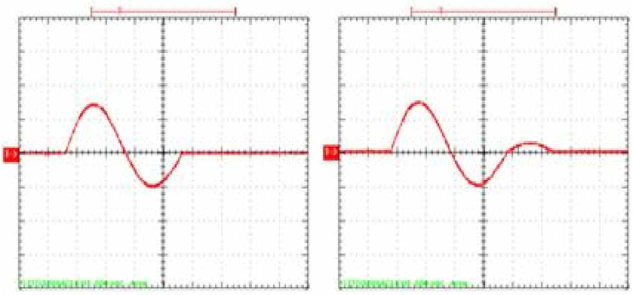


**Fig. 3.** Sample waveform of test current

However, the results are quite different for GCBs with a long minimum arcing time (~10–12 ms).

As shown in Fig. 3, the test current is reduced in the second current loop and is cut off or greatly reduced in the third current loop. This is due to the arc occurring between the contacts of a GCB. Consequently, it is difficult to satisfy the international standard that the variation of the magnitude of the current should be within 10%. Additionally, a two-parameter TRV circuit consisting of Rf and Cf is used to evaluate the breaking performance of the circuit breaker, at a rated voltage of 100 kV or less, where the maximum value of RRRV is ~2 kV/μs. However, it is difficult to generate a TRV waveform at a rated voltage of 100 kV or more, where RRRV has a value of 2 kV/μs or more.

This paper introduces the SSTF that solves all the problems mentioned above. The newly developed SSTF has a re-ignition circuit to prolong arcing, a current source circuit for compensating the magnitude of the third current loop, and a modified TRV circuit for generating an RRRV of 20 kV/μs or more.

## 2. Modification of the SSTF Circuit

In order to evaluate the SLF breaking performance for GCBs with a long minimum arcing time, a modification to the conventional SSTF circuit was done. The detailed process is described below.

### 2.1 Re-ignition circuit

The basic configuration of the prolonged arcing circuit proposed in International Standards is shown in Fig. 4 [4], [5].

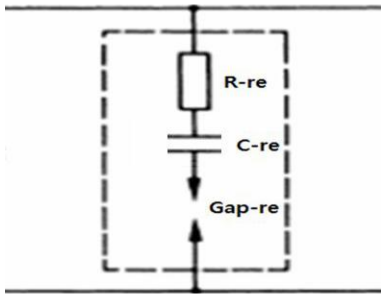



**Fig. 4.** Re-ignition circuit diagram to prolong arcing

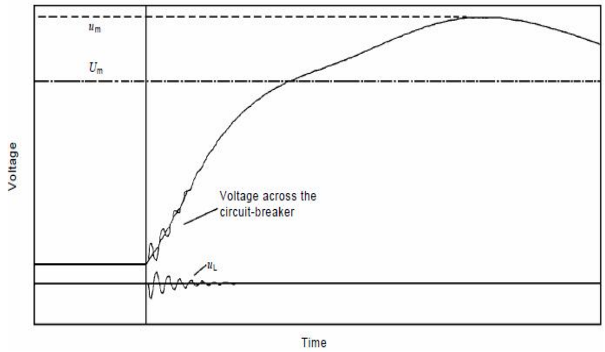



**Fig. 5.** TRV waveform for the SLF

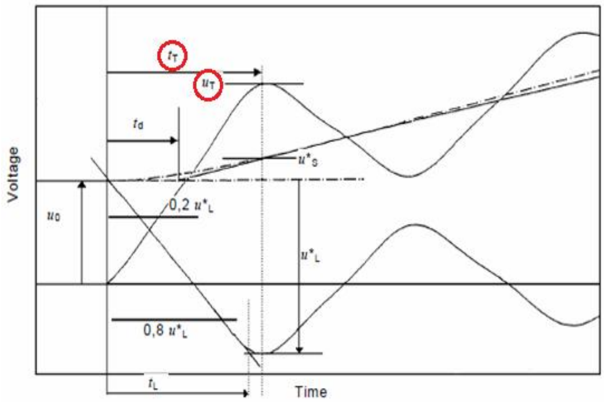



**Fig. 6.** Initial Region of the TRV

The re-ignition circuit consists of an R-C discharge circuit. The capacitor C-re charged before the testing is discharged through the gap during operation.

### 2.2 Expansion of the current source circuit

In order to compensate for the current reduction in the third current loop, it was decided to add a separate capacitor bank.

### 2.3 Application of the modified TRV circuit

In case of time delay on the source side and no delay on

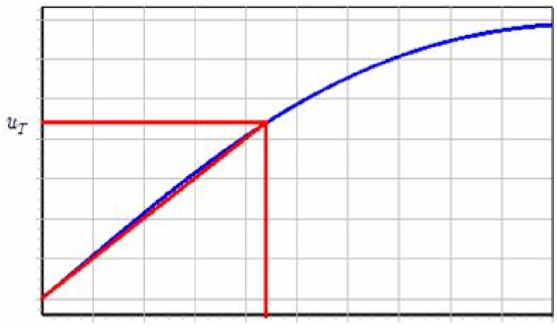
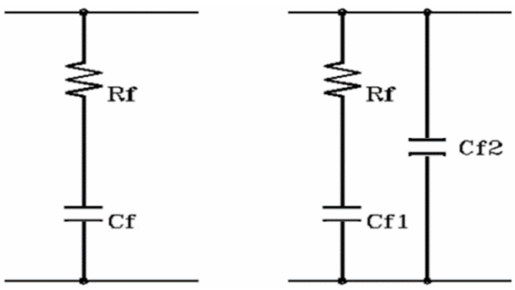



**Fig. 7.** Voltage waveform for the SLF test




Conventional TRV circuit    Modified TRV circuit

**Fig. 8.** TRV circuit diagram

the line side, the waveform of the SLF proposed in IEC 62271-100 is as shown in Fig. 5.

An enlarged representation of the initial region of TRV is shown in Fig. 6.

In the TRV waveform of the SLF, the value of the first crest is given by $(u_T, t_T)$.

The breaking performance test method for SLF is shown in Fig. 7. As shown in the figure, the TRV circuit is used to generate a TRV waveform given by $(u_T, t_L)$.

Our experiment confirmed that it was impossible to generate the RRRV more than 5 kV/μs through the TRV circuit consisting of Rf and Cf. This is because the stray capacitance of the SSTF and capacitance inside voltage divider exceed the value of Cf. Therefore, it is necessary to incorporate some modifications in the TRV circuit. In order to do this, we compared and analyzed the previous studies [6]-[9]. The purpose of this study is to implement a circuit that is as simple as possible. The modified TRV circuit diagram is shown in Fig. 8. It can be seen that a TRV circuit can be implemented by adding a capacitor element.

The modified TRV circuit was verified to be capable of generating a RRRV of 20 kV/μs after testing.

The circuit diagram of the SSTF with the modified TRV circuit is shown Fig. 9.

We can see a re-ignition circuit to prolong arcing, an additional current source circuit to compensate for the reduction in the third current loop, and a modified TRV circuit that adds Cf2 in Fig. 9.

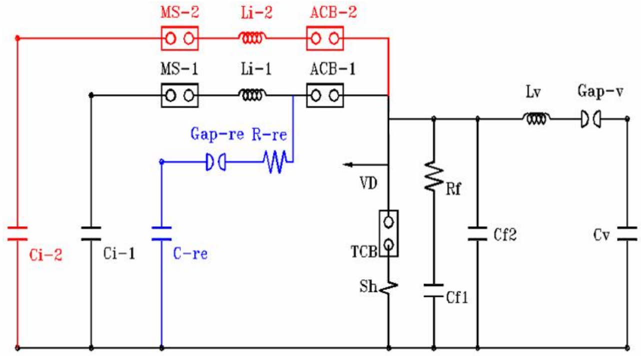



**Fig. 9.** Circuit diagram of the SSTF with the modified TRV circuit

**Table 1.** The rate of rise of the first crest value $(u_T, t_L)$

| Test duty | $u_T$ [kV] | $t_L$ [μs] | $u_T / t_L$ [kV/μs] |
|---|---|---|---|
| $L_{75}$ | 62.14 | 6.17 | 10.11 |
| $L_{90}$ | 23.0 | 2.06 | 11.17 |

**Table 2.** Values of the circuit constants of the SSTF

| Circuit | C[μF] | L[mH] | R or Rf [Ohm] | Cf1 [pF] | Cf2 [pF] |
|---|---|---|---|---|---|
| Current #1 | 60,000 | 0.118 | 0.007 | | |
| Current #2 | 30,000 | 0.235 | 0.0085 | | |
| Re-ignition | 77 | | 6.7 | | |
| Voltage | 77 | 0.98 | | | |
| TRV | | | 1300 | 2000 | 666 |

## 3. Numerical analysis

For the rating combination of 170 kV, 50 kA, and 60 Hz, the International standard for the SLF, are given in Table 1.

The circuit constant values of the SSTF for performing the test conditions of $L_{90}$ in Table 1 are given in Table 2.

The resistance values for current #1 and #2 are determined by the cabling of the inductor and capacitor bank.

A numerical analysis was performed on the circuit of the SSTF. An electromagnetic transients program (EMTP) software, ATP Draw (version 5.9p5), was used for the analysis. A circuit diagram for the analysis is shown in Fig. 10.

The current and voltage waveforms flowing through the TCB are shown in Fig. 11.

The rms current values are 69.5 kA, 54.1 kA, and 53.3 kA. The TRV waveform applied to the TCB is enlarged and shown in Fig. 12.

The RRRV and peak values are 11.6 kV/μs and 23.3 kV/2 μs, respectively. The results of the numerical analysis are calculated considering the open operation of the switch marked TCB. However, it is impossible to consider the phenomenon of the arc that arises when the circuit breaker operates. The arc phenomena arising at the arc contacts

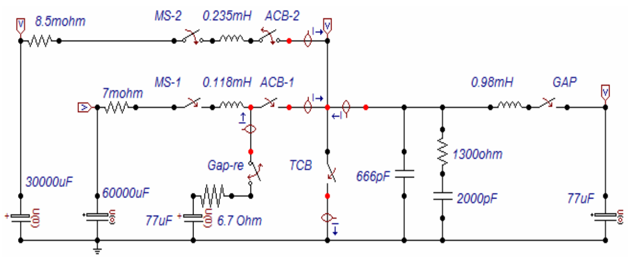



**Fig. 10.** Circuit diagram for numerical analysis

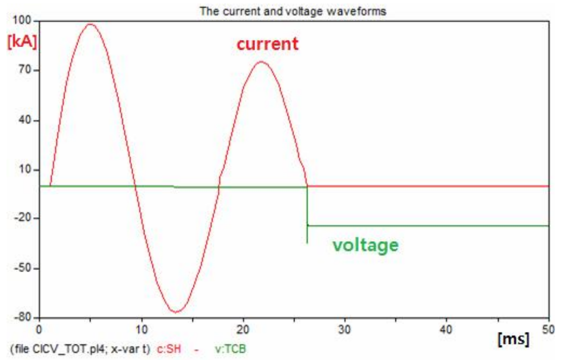



**Fig. 11.** Current and voltage waveforms

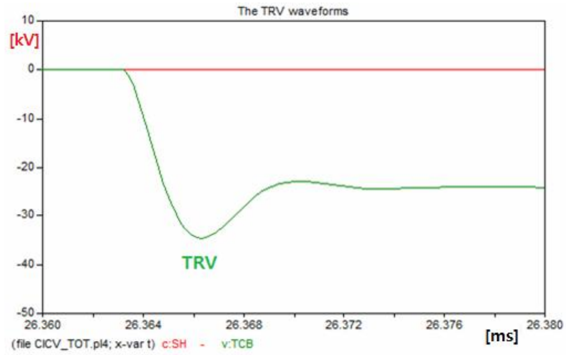



**Fig. 12.** TRV waveform

differ based on the design of the circuit breaker. Therefore, it is necessary to understand in advance that the result of the numerical analysis will differ from the measured result when the actual circuit breaker operates.

## 4. Test Results

In order to evaluate the overall operating characteristics of the newly developed SSTF, the $L_{90}$ breaking performance test was carried out on a 170-kV 50-kA 60-Hz GCB filled with $SF_6$ gas. The test results are summarized in Table 3.

The file 1520 in Table 3 is shown in Fig. 13.

The test result shows the waveform of the stroke, the trip coil current, and the test current. We can confirm from the waveform of the current that the normal operation of the

**Table 3.** Test results of GCB

| Charging Vtg. [kV] | | | | Arcing time [ms] | Current [kArms] | File |
|---|---|---|---|---|---|---|
| Ci#1 | Ci#2 | Re-ig. | Cv | | 1-st, 2-nd, 3-rd | |
| 4.2 | 4.0 | | 24 | 14.4 | 58.9, 45.4, 45.4 | 1410 |
| 4.1 | 4.0 | | 24 | 12.4 | 57.8, 44.8, 48.9 | 1439 |
| 4.0 | 3.6 | | 24 | 10.0 | 53.0, 43.6, 48.3 | 1458 |
| 4.3 | 4.2 | 55 | 24 | 16.0 | 60.1, 45.4, 44.2 | 1520 |
| 4.5 | 4.5 | 55 | 24 | 18.0 | 62.5, 45.4, 41.8 | 1541 |
| 4.6 | 4.8 | 55 | 24 | 20.0 | 64.2, 45.4, 41.8 | 1626 |
| 4.8 | 5.2 | 55 | 24 | 23.6 | 67.2, 43.0, 36.0 | 1713 |

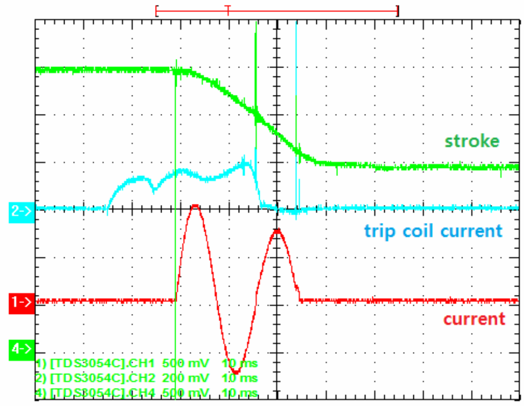



**Fig. 13.** Current test result (1520-1)

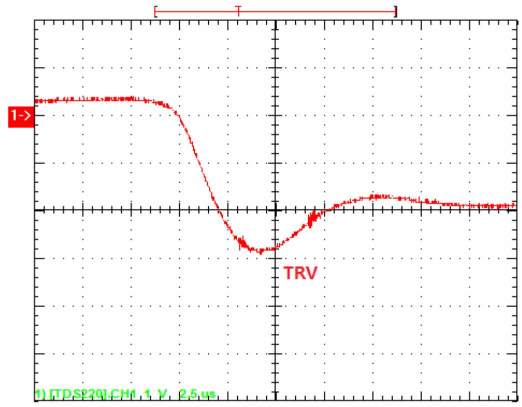



**Fig. 14.** Voltage test result (1520-2)

re-ignition circuit to prolong arcing and the increase of current in the third current loop were applied as expected.

Next, the voltage waveform supplied after the zero point of the test current is shown in Fig. 14.

From the measurement results, it can be seen that RRRV is 10.74 kV/μs (20.4 kV/1.9 μs). It can also be confirmed that the approximate value of 11.17 kV/μs specified in the IEC standard was supplied.

## 5. Conclusion

For developing a GCB, it is necessary to evaluate the thermal characteristics of the insulating gas filled in the GCB. In order to evaluate the SLF breaking performance for a GCB with a long minimum arcing time, a modification of the conventional SSTF was proposed.

The newly developed SSTF has a re-ignition circuit to prolong arcing, a current source circuit for compensating the magnitude of the third current loop, and a modified TRV circuit for an RRRV of 20 kV/μs.

An $L_{90}$ breaking performance test was performed on a 170-kV 50-kA 60-Hz GCB, and the normal operation of the SSTF was confirmed. The newly developed SSTF is expected to play an important role in developing a new GCB.

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